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Comparison of 2D-numerical Modelling of Local Scour Around a Circular Bridge Pier in Steady Current

P. Mohamed Rajab and K. Thiruvenkatasamy
Department of Harbor and Ocean Engineering, AMET University, 135 East Canal Roal (ECR),
Kanathur, 603112 Chennai, India

Abstract: In this study, to compare the numerical result of scour around a circular pier subjected to a steady current with experimental results an unstructured flexible mesh generated with rectangular flume dimension of 10 m wide, 1 m deep and 30 m long. The grain size of the sand was d_{50} = 0.16 mm, sediment size, sediment gradation = 1.16, pier diameter D = 30 mm and depth averaged current velocity, U = 0.449 m/sec are considered in the model same as the flume experimental conditions. The two dimensional MIKE21 Flow Model (FM) and Sand Transport (ST) Module which is developed by Danish Hydraulic Institute (DHI), Denmark was used in the study. The estimated scour depth obtained from this model is validated with flume experimental results and it is observed that the results of the model have good agreement with flume experimental results. In order to compare the scour depth, several simulations were made change in sediment transport model description in the numerical model viz., Engelund-Hansen Model, Engelund-Fredsoe Model and Van Rijn Model for keeping constant pile diameter D = 0.03 m and for constant depth averaged current speed U = 0.449 m/sec. The results indicate that the scour depth estimates using Engelund-Hansen method gives high (factor 0.86) which is compares well the experimental results and Engelund-Fredsøe gives factor 0.32 and Van Rijn method gives low factor 0.23 when compared with flume experimental results. And also, it is observed that the scour depth S/D is the order of 1.73 for Engelund-Hansen Model, 0.64 for Engelund-Fredsoe Model and 0.46 for Van Rijn Model Hence, this MIKE21 FM-Sand Transport Model can be used as a suitable tool to estimate the scour depth for field applications. Moreover, to provide suitable scour protection methods, the maximum scour depth is to be predicted, Engelund-Hansen method can be adopted to estimate the scour depth in the steady current region.

Key words: Scour, circular pier, numerical model, Sediment Tansport Model, MIKE211, current region

INTRODUCTION

Piles are one of the most important parts of a hydraulic structure used in pile-deck structures such as bridge piers and offshore platforms. A vertical pile is frequently employed as a foundation to support a hydraulic structure and transfer forces to the bed. The presence of a vertical pile located on an erodible bed changes the flow pattern around the pile. These changes can increase the local sediment transport and can lead to scouring around the pile. DHI (2010) Scour around a pile is caused mainly by the following three effects: horseshoe vortex combined with the down flow in front of the pile, vortex shedding at the back of the pile and contraction of streamlines at the side edges. The horseshoe vortex (combined with the down flow) and the contraction of streamlines are the key elements for scour in the case of a steady current. Scour around a pile in steady currents has been investigated quite extensively experimentally particularly in the context of scour at bridge piers. Roulund *et al.* (2005). This research is also shown that, the sour depth is influenced by various factors, the most important of which are: the ratio of boundary-layer depth to pile size, h/D (the scour depth, S/D increases with increasing h/D), Shields parameter θ (S/D generally increases with increasing θ, except that it experiences a slight dip after the scour regime changes from the clear-water scour to live-bed scour), gradation of the sediment (S/D decreases with increasing gradation), ratio of sediment size to pile diameter, D/D (S/D increases with increasing D/d): Froude number (based on the pile diameter) (S/D increases with increasing Froude number): Shape factor; and alignment factor (Sumer, 2007).

In the recent years, many researchers investigated the complex flow pattern and sediment transport around bridge pier. Dou *et al.* and Dou and Jones carried ou numerical calculations to evaluate the rate of sediment transport for local scour around a bridge pier (Sumer,

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Corresponding Author: P. Mohamed Rajab, Department of Harbor and Ocean Engineering, AMET University, 135 East Canal Road (ECR), Kanathur, 603112 Chennai, India

2007). Olsen and Kjellesvig, suggested a combined 3-D hydraulic and sediment transport models for the suspended sediment concentration for scour modeling which was used to simulate the flow and scouring around a single cylindrical pier. The bed concentration formula was used for the equilibrium sediment concentration near the bed. Since, the equation consists of some empirical results did not provide enough information about unsteadiness in the flow (Dixen *et al*., 2013). By Sumer (2001) the steady-current scour tests were carried out experimentally using flume with dimension of 4 m wide, 1 m deep and 28 m long for the two kinds of pile diameters D = 90 and D = 30 mm. The depth of the sand layer in the flume was 25 cm and the water depth of 0.6 m was maintained in the flume. The grain size of the sand was d_{50} = 0.16 mm. The results were indicated that for 90 mm-pile gives a scour depth of S/D = 1.21 whereas the 30 mm-pile gives somewhat larger scour depth, S/D = 2.0.

In the present investigation in order to compare above experimental results, the development of scour around a circular pier subjected to a steady current were studied numerically using MIKE21 Flow Model, FM and Sand Transport (ST) Module developed by Danish Hydraulic Institute (DHI), Denmark using unstructured flexible mesh generated with rectangular flume dimension of 10 m wide, 1 m deep and 30 m long The numerical simulation's results are validated with the laboratory experiments by Sumer *et al*. and The flume dimension other model input parameters were used same as described in Sumer *et al*. (Baykal *et al*., 2014a, b). Several simulations were made to study scour development for change in sediment transport model description in the numerical model viz: Engelund-Hanse Model, Engelund-Fredsoe model and VanRijn model for constant pier diameter = 0.03 m and constant depth average current speed, U = 0.449 m/sec .

MATERIALS AND METHODS

Numerical model approach

Mike 21 Flow Model-FM and sand transport module: The numerical simulations of scour around a circular pile in a steady current were carried using the MIKE21 Flow Model, FM and Sand Transport (ST) Module whihc is a numerical tool developed by Danish Hydraulic Institute (DHI), Denmark. The MIKE21 Flow Model FM, Sand Transport Module (ST) is the module for the calculation of sediment transport capacity and related initial rates of bed level changes for non cohesive sediment (Sand) due to currents or combined waves-currents (Sumer, 2014). The ST Module calculates sand transport rates on a flexible mesh (unstructured mesh) covering the area of interest on the basis of the hydrodynamic data obtained from a simulation with the Hydrodynamic Module (HD) and possibly wave data(provided by MIKE21 SW) together with information about the characteristics of the bed material. The simulations are performed on the basis of the hydrodynamic conditions that correspond to a given bathymetry. It is possible to include feedback on the rates of bed level changes to the bathymetry such that morphological evolution can be carried out.

The sand transport description in pure currents is a state-of-the art model capable of including lag-effects from the flow and the suspended load in the morphological environment. The lag-effects on the suspended load are determined from an advection-dispersion equation that includes effects from over-loading or under loading of the concentration of the suspended sediment and the helical flow pattern. This approach is often referred to as a non-equilibrium sediment description where erosion and deposition of the bed is controlled by under-loading and over-loading of the suspended sediment in the water column. The bed load description includes gravitational effects forced from longitudinal and lateral bed slopes. Three different sand transport formula are available for determination of the equilibrium total load transport of sediment (bed load capacity and suspended load) theory viz: Engelund-Hansen, Engelund-Fredsøe and Van Rijn. The equilibrium sand transport capacities are calculated on the basis of local water depth, mean horizontal velocity component, Manning's number/Chezy's number and properties of the bed material such as median grain size and gradation which may vary throughout the model area.

Solution techniques: The modeling system based on the numerical solution of the two dimension shallow water equations-the depth integrated incompressible Reynolds averaged Navier Stokes equations. Thus, the model consists of continuity, momentum, temperature, salinity and density equations. In horizontal domain both Cartesians and spherical coordinates can be used. The appropriate governing equations for studying water movement in coastal areas are the two dimensional shallow water equations. These are obtained by vertically integrating the three-dimensional Navier Stokes equations of motion making the following simplified assumptions: the flow is incompressible, the flow is well mixed (no variation in density), vertical accelerations are negligible, bed stress can be modeled. Simulation of hydrodynamics is based on these shallow water equations given as: Continuity equation:

$$\frac{\partial z}{\partial t}+\frac{\partial uh}{\partial x}+\frac{\partial vh}{\partial y}=0 \qquad (1)$$

Equation of motion in X-direction:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+g\frac{\partial z}{\partial x}+\tau_{bx}-C_f v-E_c\nabla^2 u=0 \qquad (2)$$

Equation of motion in Y-direction:

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+g\frac{\partial z}{\partial y}+\tau_{by} \qquad (3)$$
$$+C_f u-E_c\nabla^2 v=0$$

Where:

z = Water surface elevation
h = Total water depth (z+d)
u = v-Velocity components in x and y direction
C_f = Coriolis force
E_c = Eddy viscosity coefficient

The spatial descretization of the primitive equations is performed using a cell centered finite volume method. The spatial domain discretized by subdivision of the continuum into non overlapping element/cell. In horizontal plane an unstructured grid is used comprising of triangles and quadrilateral element. An approximate Riemann Solver is used for the computation of convective fluxes which makes it possible to handle discontinuous solutions. For the time integration an explicit scheme is used.

Sediment transport formulae: Sediment transport capacity in uniform shear flow has been extensively investigated over the years. The sediment transport formulas used for the calculation of bed load and suspended load transport (equilibrium concentration) which are implemented in the MIKE21 FM, sand transport module. All sediment transport formulas described herein exclude the effect of riverbed porosity which is included in the continuity equation for update of bed level instead. Some of the formulas only predict total load (bedload+suspended load) whereas information about both bed load and suspended load is required. The total load formulas can still be applied by using the calibration factors k_b and k_s for bed load and suspended load, respectively in order to differentiate between the two modes of transport. Due to the non-uniform vertical distribution of the suspended sediment concentration, the effective fall height of grains will be different from the mean fall heignt h/2 (where h is water depth). For a uniform vertical concentration profile, the time scale for settling is defined as h/w_s (ws is settling velocity). With information about the Rouse number Z, the actual concentration profile can be predicted and therefore a better estimate for the settling time scale ts can be obtained if using the height of the centroid. However, the times scale effect on the settling has already been included in the modeling using the described profile functions and $\phi(\eta_o)$ factor on the sink/source term in the advection-dispersion equation for the concentration of the suspended sediment. The shields parameter θ is defined as:

$$\theta=\frac{\tau}{\rho g(a-1)d_{50}} \qquad (4)$$

Where:

τ = The flow shear stress
ρ = Density of water (kg/m^3)
g = Acceleration of gravity, 9.81 m^2/sec
s = ρ_s/ρ, Relative density of the sediment
ρ_s = Density of sediment for quartz sand 2650 (kg/m^3)

Flow shear stess is divided into the form drag τ'' and skin friction τ'. The total shear stress $\tau = \tau'+\tau''$ is estimated from the local flow velocity u and the local Chezy number, C as $\tau = \rho g V^2/C^2$ For skin friction the following approxiamate friction formula is applied unless otherwise calculated (i.e., in the model of Van Rijn or the model of Engelund-Fredsoe where more sophisticated models are used to describe the physical processes: $\theta' = 0.06+0.4.\theta^2$. The non-dimensional sediment transport rate is defined as:

$$\Phi=\frac{S}{\sqrt{(s-1)gd^3}}$$

Where:

S = Sediment transport (bed load, total or suspended load)
d = Grain size
Φ = Non-dimensional sediment transport

Engelund-Hansen Model: The model by Engelund-Hansen is a total load model that needs user-specified information in order to divide the sediment transport into bed load and suspended load. The transport rates are obtained from the relations:

$$S_{bl} = k_b.S_{tl} \quad \text{and} \quad S_{sl} = k_s.S_{tl}$$

Where:

S_{bl} = Bed load transport (m^2/sec)
k_b = Bed load calibration factor
S_{sl} = Suspended load transport (m^2/sec)
k_s = Suspended load calibration factor
S_{tl} = Total load transport (m^2/sec)

Total sediment transport is obtained by:

$$S_{tl} = 0.05\frac{C^2}{g}\theta^{5/2}\sqrt{(s\text{-}1)gd_{50}^3}$$

where, s = Relative density of the sediment. The equilibrium concentration is simply specified as the suspended load dived by the water flux and converted from volumetric concentration to mass concentration:

$$c_e = \frac{S_{sl}}{V.h}.s.10^6$$

Where:

C_e = Equlibrium mass concentration (g/m^3)
C = Chezy number (m$^{1/2}$/sec)
V = Velocity (m/sec)

Van-Rijn Model: Van-Rijn proposed the following models for sediment of bed load and suspended load:

$$S_{bl} = 0.053\frac{T^{2.1}}{D_*^{0.3}}\theta^{5/2}\sqrt{(s\text{-}1)gd_{50}^3}$$

where, T is the non-dimensional transport stage parameter given by:

$$T = \left(\frac{u_f^{'}}{u_{f,c}}\right)^2 \text{-}1$$

The critical friction velocity $u_{f,c}$ is determined from:

$$u_{f,c} = \sqrt{\theta_c\,(s\text{-}1)gd_{50}}$$

The effective friction velocity is estimated from:

$$u_f^{'} = V\frac{\sqrt{g}}{C^{'}}$$

where, the resistance, Chezy number from skin friction is based on a logarithmic velocity assuming a certain bed roughness.

$$C^{'} = 18\log\left(\frac{4h}{d_{90}}\right)$$

and d* is the non-dimensional particle diameter is determined from:

$$D_x = d_{50}\left(\frac{(s\text{-}1)g}{\upsilon^2}\right)^{1/3}$$

Suspended sediment transport occurs the friction velocity u_f only if one of the following criteria is satisfied:

$$u_f > \frac{4w_s}{D_*} \text{ for } D_* < 10$$

$$u_f > 0.4w_s \text{ for } D_* > 10$$

The reference level at which the bed concentration is determined is expressed as:

$$a = \max\begin{pmatrix} 0.01h \\ 2d_{50} \end{pmatrix}$$

The volumetric bed concentration is obtained from the relation:

$$c_a = 0.015.\frac{d_{50}\,T^{1.5}}{a\,D_*^{0.3}}$$

A correction coefficient, denoted β is applied to the hydrodynamic diffusion coefficient in order to transform the coefficient into a diffusion coefficient for the suspended sediment:

$$\beta = 1+2\left(\frac{w_s}{u_f}\right)^2$$

Van Rijn defines a correction factor φ for the concentration profile which is determined by:

$$\varphi = \frac{5}{2}\left(\frac{w_s}{u_f}\right)^{0.8}\left(\frac{c_a}{c_o}\right)^{0.4}$$

where, C_o expressed as volumetric concentration and is the concentration corresponding to firm packing of the sediment i.e:

$$c_o = 0.65\frac{m^3}{m^3}$$

When applying the correction coefficients defined above, a Rouse suspension parameter Z can be obtained by:

$$Z = \frac{w_s}{\beta\kappa u_f} + \varphi$$

Then, the depth-integrated transport of suspended load is computed as:

$$S_{sl} = f.c_a.V.h$$

The correction factor for suspended load is obtained from:

$$f=\frac{\left(\frac{a}{h}\right)^{Z}-\left(\frac{a}{h}\right)^{1.2}}{\left(1-\frac{a}{h}\right)^{2}(1.2-Z)}$$

Where:

f = Correction factor for suspended load
c_a = Volumetric bed concentration, the equilibrium concentration
c_e = Calculated based on variation of Rouse number Z and water depth, h

Engelund-Fredsoe Model: The probability of a moving sediment grain can, according to Engelund-Fredso 1976, be determined by the expression:

$$p=\left[1+\left(\frac{\frac{\pi}{6}\mu_d}{\theta'-\theta_c}\right)^{4}\right]^{-1/4},\theta'>\theta_c$$

The dynamic friction coefficient $\mu_d$is assumed to be equal to μ_d = 0.51 = tan 27°. The non-dimensional skin shear stress is defined by:

$$\theta'=\frac{u_f'^{2}}{(s-1)gd_{50}}$$

where, the friction velocity related to skin friction is calculated from the assumption of a logarithmic velocity profile:

$$u_f'=\frac{V}{6+2.5\mathrm{Ln}\left(\frac{h}{2.5d_{50}}\right)}$$

The bed load transport rate is estimated from:

$$S_{bl}=5p.(\sqrt{\theta'}-0.7\sqrt{\theta_c})\sqrt{(s-1)gd_{50}^{3}}$$

The reference concentration near the bed is calculated from an empirical relation obtained by Zyserman and Fredsoe:

$$c_b=\frac{0.33(\theta-\theta_c)^{1.75}}{1+\frac{0.331}{0.46}(\theta-\theta_c)^{1.75}}$$

The velocity profile is assumed to be:

$$u(\eta)=\frac{\sqrt{g}}{0.4C}\ln\left(\frac{\eta}{\eta_o}\right)$$

where, the no-slip level η_o is obtained from:

$$\eta_o=\exp\left(\eta_o-1-\frac{0.4C}{\sqrt{g}}\right)$$

and solved by iteration. The normalized vertical concentration profile is specified in the following way:

$$c(\eta)=\left(\frac{1-\eta}{\eta}.\frac{a}{1-a}\right)^{z}$$

where the reference level a is defined by:

$$a=\frac{2.d_{50}}{h}$$

The Rouse suspension parameter Z is defined as:

$$Z=\frac{w_s}{\kappa u_f}$$

The suspended load transport rate S_{sl} is obtained from:

$$S_{sl}=c_b\,Vh\int_{\eta_0}^{1}u(\eta).c(\eta)d\eta$$

The equilibrium mass concentration c_e, determined from:

$$c_e=\frac{S_{sl}}{Vh}s.10^{6}$$

Morphological model: The morphological model is combined hydrodynamic and sediment transport mode. The hydrodynamic flow filed is updated continuously according to the change in the bed bathymetry. The solution of the hydrodynamics is solved at a certain time step prior to the sediment transport equations. Subsequently, a new bed level is computed and the hydrodynamic model proceeds with the next time step.

Sediment continuity equation: The key parameter for determination of the bed level chains the rate of bed level change ($\partial z/\partial t$)at the element cell centres. This parameter can be obtained in a number of ways but in general all methods are based on the Exner equation (sediment continuity equation) which can be written:

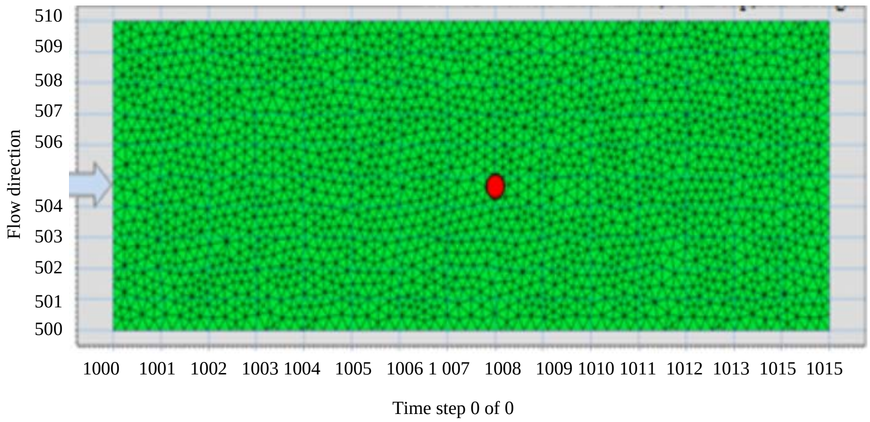

Fig. 1: Model Domain-Flexible Mesh-MIKE21 Model; Circle pier location, generation flexible mesh all are contant depht

$$-(1-n)\frac{\partial z}{\partial t}=\frac{\partial S_x}{\partial x}+\frac{\partial S_y}{\partial y}-\Delta S$$

Where:

n = Bed porosity

z = Bed level

t = time

S_x = Bed load or total load transport in the x-direction

S_y = Bed load or total load transport in the y-direction

x, y = Horizontal Cartesian coordinate

ΔS = Sediment sink or source rate

For an equilibrium description of the sediment transport, the sink/source term is zero unless lateral sediment supply is included in the model. For a non-qulibrium description, i.e., solution of an advection-dispersion equation for the suspended load, the sediment sink/source term can be written (Fig. 1):

$$\Delta S = \Phi_o(\eta_o)w_s(c-c_e)$$

Where:

η_o = Normalised no slip level abov the bed

φ_o = Unit profile function for the sediment concentration

w_s = Setlling velocity for the suspended sediment

c = Depth-averaged sediment concentration

c_e = Depth-average equilibrium concentration

The term expresses that sediment deposits at the bed if the actual concentration in the water column is larger than the equilibrium concentration and the opposite if it is lower. After having solved the advection-dispersion equation, the term can be calculated directly at all the element cell centers such that only the concentration from the bed load needs to be included in order to find the bed level rate.

Model setup: By Sumer *et al.* (2001) the steady-current scour tests were carried out experimentally using flume with dimension of 4 m wide, 1 m deep and 28 m long for the two kinds of pile diameters D = 90 and D = 30 mm. The depth of the sand layer in the flume was 25 cm and the water depth of 0.6 m was maintained in the flume. The grain size of the sand was d_{50} = 0.16 mm. The results were indicated that for 90 mm-pile gives a scour depth of S/D = 1.21 whereas the 30 mm-pile gives somewhat larger scour depth, S/D = 2.0. In order to compare these experimental results, the numerical simulations were carried out using MIKE21 using unstructured flexible mesh generated with rectangular flume dimension of 10 m wide, 1 m deep and 30 m long. The water depth of 1.0 m was maintained in the flume. The grain size of the sand was d_{50} = 0.16 mm, sediment size, sediment gradation = 1.16, pile diameter D = 30 and D = 90 mm and depth averaged current velocity, U = 0.449 m/sec are considered in the model. The model setup with a circular pier was placed at the centre of the domain shown in Fig. 1.

Sensitivity studies-Sand Transport (ST) Module: Sensitivity studies are carried out by varying the parameters in the MIKE 21 Flow Model, FM and Sand Transport (ST) Module and their relative performances with bed resistance in terms of Manning's number and Eddy viscosity in-terms of Smogrinsky coefficient examined and their results are shown in Fig. 2 a and b. The pier diameter D = 0.03 m, sediment Gradation = 1.16, median particle size d_{50} = 0.16 mm were given in the model. For the sensitivity study, the steady current taken as U = 0.449 m/sec. Figure 2a and b shows that the relative scour depth decreases with increasing the Manning's resistance coefficients (decrease bed resistance) and increases with increasing Smogrinsky coefficients in eddy terms.

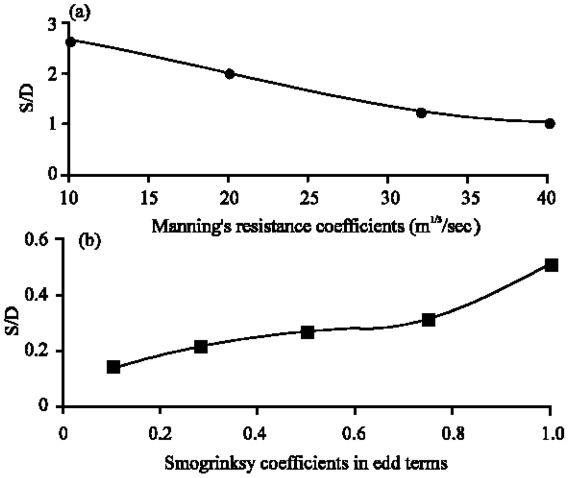

Fig. 2: Variation of Scour depth with changing: a) Manning's resistance and b) Smogrinsky coefficient in Eddy terms (Pile Diameter, D = 0.03 m)

Validation of model results: The simulated results of scour depth using 2D-numerical model was calibrated and evaluated with the laboratory experiments by Sumer *et al.* with the following conditions in the model input, such as the pier diameter D = 0.03 m, Depth average current speed U = 0.449, sediment size d = 0.16 mm, water depth = 1.0 m. Calibration parameters in the model are bed resistance coefficient that has introduced as manning numbers for the value of 20 $m^{1/3}$/sec and Eddy viscosity coefficient in-terms of Smogrinsky coefficient of 1. The estimated relative scour depth using numerical model show that scour depth S/D = 1.73 for 30 mm pier diameter which is good agreement with flume experimental results by Sumer *et al.* were indicated that, scour depth S/D = 2.0 for 30 mm-pile.

RESULTS AND DISCUSSION

Three kinds of simulations were carried out in a steady current field, Case 1: change in the sediment transport model description, i.e., Englund and Hansen formulae, Engelund-Fredsϕe method and Van-Rijn method for the pile diameter D = 0.03 m, depth averaged current velocity, V = 0.449 m/sec, Case 2: change in the depth average current speed for constant pier diameter D = 0.03 m Case 3: change in pier diameter for constant depth averaged current velocity U = 0.449 m/sec.

By sumer *et al.* the steady-current scour tests were carried out experimentally using flume with dimension of 4 m wide, 1 m deep and 28 m long for the two kinds of pile diameters D = 90mm and D = 30 mm. The depth of the sand layer in the flume was 25 cm. The grain size of the sand was d_{50} = 0.16 mm. The results for the steady current of 0.44 were indicated that for 90 mm-pile gives a scour depth of S/D = 1.21 whereas the 30 mm-pile gives somewhat larger scour depth, S/D = 2.0. In order to compare this experimental results in the present study, numerical simulations were carried out using MIKE21 FM-sand transport module with flexible mesh generated in the rectangular flume with dimension10 m wide, 1 m deep and 30 m long. The same sediment size of 0.16 mm, sediment gradation of 1.16, two kind of pile diameter of D = 30 mm and D = 90 mm and depth averaged current velocity of 0.449 m/sec are considered in the model as in the case of current alone experiments. (Sumer, 2007).

Table 1: Variation of scour depth with change in model description for pier diameter (D = 0.03 m)

Sediment transport model description	Equilibrium scour depth (m)	Relative scour depth (S/D)	Factor compared with experimental results by Sumer *et al.* (2001)
Engelund-Hansen Model	0.052	1.73	0.86
Engelund-Fredsøe Model	0.019	0.64	0.32
Van Rijn Model	0.015	0.46	0.23

Case 1; Change in sediment transport formulae in model description: The scour depth simulated based on three different model descriptions viz: Engelund and Hansen, Engelund-Fredsøe and VanRijn method are estimated using MIKE21 FM Sand transport model shown in Fig. 3 and presented in Table 1. It shows that the scour depth estimates gives wide variation among three methods. The relative scour depth estimates using Engelund-Hansen method is good agreement with experimental results by Sumer, 2007. The scour depth estimated using Engelund-Hansen method gives higher factor of 0.86 and Engelund-Fredsoe method gives factor of 0.32 and Van Rijn method gives low factor of 0.23 when compared with experimental results by Sumer (2007) and also, it is observed that the scour depth S/D is order of 1.73 for Engelund-Hansen model, 0.64 for Engelund-Fredsoe Model and 0.46 for VanRijn Model. The estimated scour depth using Engelund-Hansen method is close agreement with experimental results by Sumer *et al.* (2014) and Engelund-Hansen method can be used to estimate the scour depth.The time development of scour based on the above three model

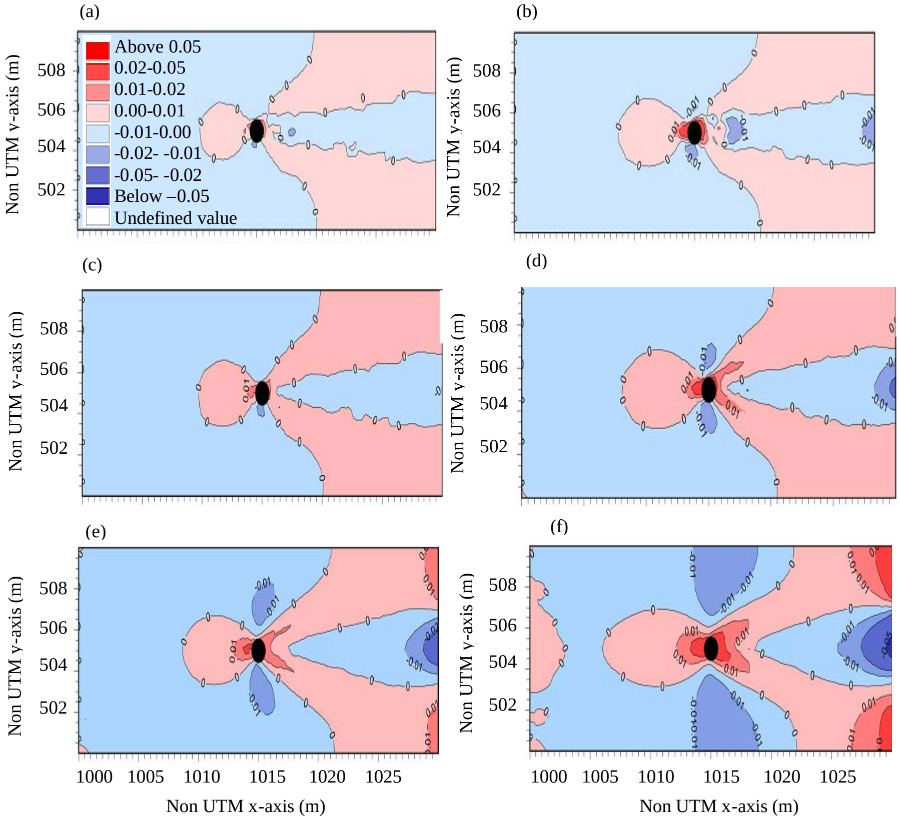

Fig. 3: Scour and deposition pattern around the circular pier after 1:30 h and 4:00 h of simulation in a, b) Van Rijn Model; c, d) Engelund-Fredsoe Model and e, f) Engelund-Hansen Model (Values in Positive-Deposition and Negativ-Scour)

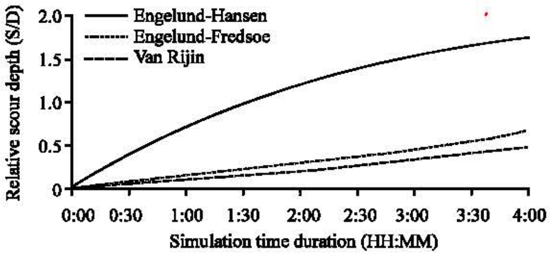

Fig. 4: Variation of the time development of scour for constant pier diameter, D = 0.03 mbased on three different model description

description is shown in Fig. 4. The result indicate that the equilibrium scour depth attains in Engelund-Hansen Model in 3 h time duration where as the equilibrium scour depth increase with increasing the simulation time. The variation of relative scour depth with respect to change in depth average current speed and change in Froude number for constant pier is shown Fig. 5a and b, respectively.

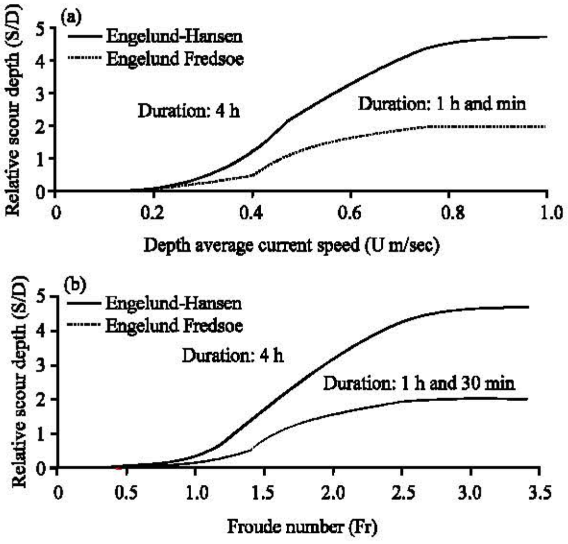

Fig. 5: Variation of relative scour depth in after 1 h and 30 min and after 4 h of simulation: a) Change in depth average current speed and b) Change Froude number for constant pier

CONCLUSION

The present investigation has shown that the scour results of the numerical model such as MIKE21 FM sand transport module have good with estimated experimental results of previous study, hence this numerical can be used as a suitable tool to estimate the scour depth. In order to provide suitable scour protection methods, the maximum scour depth is to be predicted, Engelund-Hansen method can be used to estimate the scour depth.

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REFERENCES

Baykal, C., B.M. Sumer, D.R. Fuhrman, N.G. Jacobsen and J. Fredsoe, 2014b. Numerical investigation of flow and scour around a vertical circular cylinder. Phil. Trans. R. Soc. Math. Phys. Eng. Sci., 373: 1-21..1

Baykal, C., B.M. Sumer, D.R. Fuhrman, N.G. Jacobsen and J. Fredsoe, 2014a. Numerical modelling of backfilling process around monopiles. Proceedings of the 34th International Conference on Coastal Engineering, June 15-20, 2014, Curran Associates, Inc., Seoul, South Korea, pp: 1-10.

DHI., 2010. An integrated modelling system for littoral process and coastline kinetics: Shore introduction and tutorial. Danish Hydraulic Institute, Copenhagen, Denmark.

Dixen, M., B.M. Sumer and Jorgen Fredsoe, 2013. Numerical and experimental investigation of flow and scour around a half-buried sphere. Coastal Eng., 73: 84-105.

Roulund, A., B.M. Sumer, J. Fredsoe and J. Michelsen, 2005. Numerical and experimental investigation of flow and scour around a circular pile. J. Fluid Mechanics, 534: 351-401.

Sumer, B.M., 2007. Mathematical modelling of scour: A review. J. Hydraul. Res., 45: 723-735.

Sumer, B.M., 2014. A Review of Recent Advances in Numerical Modelling of Local Scour Problems. In: Scour and Erosion Proceedings of the 7th International Conference on Scour and Erosion, Perth, Australia, 2-4 December 2014, Cheng, L., S. Draper and H. An (Eds.). CRC Press, Boca Raton, Florida, USA., ISBN:978-1-138-02732-9, pp: 61-70.